International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 6 Issue 6, September-October 2022 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Power Quality Improvement: Analysis and Implementation of Custom Power Device Unified Power Quality Conditioner (UPQC)

Sunil Kumar[1], Ashish Bhargava[2]

[1]Student, [2]Professor,

[1,2]Bhabha Engineering Research Institute, Bhopal, Madhya Pradesh, India

ABSTRACT

Power Quality (PQ) has been a source of concern for utilities at all levels of consumption. Power electronic gadget development has had a significant influence on the quality of electric power supply. The functioning of nonlinear loads creates harmonics, which degrades the distribution system's quality. In such instances, both utilities and end consumers of electric power are becoming more worried about power quality. This implies that just a few steps must be made in order to enhance power quality. The primary emphasis of this study is on UPQC, which is a mix of series and shunt active power filters. The series APF reduces voltage-based distortions, while the shunt APF reduces current-based distortions. UPQC reduces voltage and current-based aberrations simultaneously and independently. UPQC enhances power quality by correcting for both harmonics and load current, resulting in sinusoidal source current and load voltage at the appropriate voltage level. MATLAB/Simulink was used to simulate the series APF, the shunt APF, and the UPQC.

KEYWORDS: *Power Quality; Unified Power Quality Conditioner; Active Power Filter; Voltage Source Inverter; Total Harmonic Distortion*

How to cite this paper: Sunil Kumar | Ashish Bhargava "Power Quality Improvement: Analysis and Implementation of Custom Power Device Unified Power Quality Conditioner (UPQC)" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-6 | Issue-6, October 2022, pp.1964-1971, URL: www.ijtsrd.com/papers/ijtsrd52195.pdf

IJTSRD52195

1. INTRODUCTION:

Today power quality has become the most vital factor for both suppliers and customers due to the deregulation of the electric power energy market. Efforts are being made to improve the power quality. Power electronic valves are the basis of those custom power devices such as the state transfer switch (STS), active filters and converter based devices (Awad et al., 2003). The active filter technology is now mature for providing compensation for harmonics, reactive power, and/or neutral current in ac networks. Active Filters are also used to eliminate voltage harmonics, control terminal voltage, reduce voltage flicker, and improve voltage balance in three-phase systems (Bhim Singh et al.,1999). The reactive power control theory for three-phase systems with or without neutral wire, is valid for both steady state and transients (Akagi et al., 1983).

A SPLL model uses a lag or lead loop controller in order to analyse the system performance and filtering characteristics, these characteristics are analysed by the use of bode diagrams and root-locus methods. The practical aspect of the SPLL (S. R. Naidu et al., 2004) implementation has also been discussed. The operating principle and design considerations of a SPLL under practical conditions are voltage unbalance, voltage harmonics, frequency change, phase jumps and sampling delay. A series active power filter working as a sinusoidal current source, is considered in phase with the mains voltage. The amplitude of the fundamental current in the series filter is controlled with the help of error signal generated between the load voltage and a pre-established reference. The control provides the effective correction of power factor, harmonic distortion, and load voltage regulation (Juan W. Dixon et al., 1997). DVR principles and voltage restoration methods at the point of common coupling (PCC) were analysed with different voltage injection methods (ChellaliBenachaiba et al., 2008). Dynamic voltage controller with hysteresis controller was

analysed using discrete Fourier transform (DFT) scheme for sag and swell detection. (F.A.L Jowder et al., 2007).

A control algorithm for the dynamic voltage restorer (DVR) is used to mitigate the power quality problems in terminal voltage. Two PI (proportional integral) controllers are used each to regulate the dc bus voltage of DVR and the load terminal voltage respectively (Bhim Singh et al., 2011). The fundamental component of the terminal voltage is derived using the synchronous reference frame theory. A three-phase Series Active Power Filter is modelled as Power Quality Conditioner using a simplified control algorithm. Series APF compensates supply voltage unbalance and harmonics in such a way that they do not reach the load end resulting in low THD at the load voltage (M. A. Chaudhari et al., 2012).

The instantaneous reactive power theory, also known as p–q theory based on a new control algorithm is analysed for 3-phase 4-wire (Mehmet Ucar et al., 2008) and 4-leg shunt active power filter (APF) to suppress harmonic currents, compensate reactive power, neutral line currents and balance the load currents under unbalanced non-linear load and non-ideal mains voltage conditions.

Unified Power Quality Conditioner (UPQC), is an amalgamation of series APF and shunt APF. A control strategy based on unit vector template is explained in this paper with the focus on the mitigation of voltage harmonics present in the utility voltage (V.Khadkikar et al., 2006). The steady state analysis of unified power quality conditioner (UPQC) was performed. The mathematical analysis is based on active and reactive power flow through the shunt and series APF, wherein series APF can absorb or generate the active power whereas the reactive power requirement is totally handled by shunt APF.

The UPQC (Yash Pal et al., 2011) is realized by integration of series and shunt active power filters (APFs) sharing a common dc bus capacitor. The shunt APF is realized using a three-phase, four leg voltage source inverter (VSI) and the series APF is realized using a three-phase, three legs VSI.

2. Unified Power Quality Conditioner (UPQC):

The Unified Power Quality Conditioner (UPQC) is a multifunctional power conditioner that may be used to adjust for several power source voltage disturbances, voltage variations, and to prevent harmonic load current from entering the power system. It is a specialised power gadget intended to reduce the effects of disturbances on the performance of sensitive loads. UPQC is made up of two voltage-source inverters with a common dc connection that may be single-phase, three-phase three-wire, or three-phase four-wire [2]. In the series active power filter (APF), one inverter is controlled as a variable voltage source, while another inverter is controlled as a variable current source in the shunt active power filter (APF). The Active Filter in series adjusts for voltage supply irregularities (e.g., including harmonics, imbalances, sag, swell, flickers, negative and zero sequence components). The shunt filter adjusts for load current distortions (such as those generated by harmonics or imbalances), reactive power, and dc link voltage control.

3. CUSTOM POWER DEVICES

The introduction of power electronic loads has raised much concern about power quality problems caused by harmonics, distortions, interruptions, and surges. The use of electronic devices increases the power quality problem Equipment such as large industrial drives (e.g., cycloconverters) generate significantly high voltage and current (inter-, sub-) harmonics and create extensive voltage fluctuation. The addition of electronic devices is addition to power quality problem.

The application of harmonic filters and SVCs to radial transmission systems can offer partial solution to high THD levels and voltage fluctuations. Yet, the lack of dynamic capabilities of these devices limits them to bulk correction. In addition, they might be effective in one application but fail to correct other power quality issues.

Hingorani introduced the concept of custom power as the solution to V, P, and Q (voltage, active power, reactive power) compensation and power quality problems at the expense of high cost and network complexity. As FACTS controllers improve the reliability and quality of power transmission by simultaneously enhancing both power transfer capacity and stability custom power devices enhance the quality and reliability of power delivered to the customer. With a custom power device, a customer (e.g., a sensitive load) will be able to receive a prespecified quality of electric power with a combination of specifications including but not limited to:

- Magnitude and duration of over and under voltages with specified limits,
- Low harmonic distortion in the supply, load voltages, and currents.
- Small phase imbalance,
- Low flicker in the supply voltage,
- Control of power interruptions, and
- Control of supply voltage frequency within specified limits.

Classification of Custom power devices are based on their power electronic controllers, which can be either of the network reconfiguration type or of the compensation type. The network reconfiguration devices also called switchgear include the solid state and or static versions or current limiting, current breaking, and current transferring components. The compensation type custom power devices either compensate a load (e.g., correct its power factor, imbalance) or improve the quality for the supply voltage (e.g., eliminate its harmonics). They are either connected in shunt or in series or a combination of both. Custom power devices are classified as follows:

- Network – reconfiguration custom power devices include
- Solid state current limiter (SSCL),
- Solid – state breaker (SSB), and
- Solid state transfer switch (SSTS) Compensation-custom power devices include
- Distributions STATCOM (DSTATCOM),
- Dynamic voltage restorer / regulator (DVR), and
- Unified power quality conditioner (UPQC).
- Custom power devices are designed to improve the quality of power at their point of installation of the power distribution system. They are not primarily designed to improve the power quality of the entire system

3.1. UPQC Components:

The series inverter (voltage-source inverter) is linked in series with the AC line through a series transformer and works as a voltage source to alleviate voltage aberrations. UPQC reduces supply voltage flickers and load terminal voltage imbalances. Pulse width modulation is used to control the output of a series inverter (PWM). Because of its simplicity of implementation, hysteresis band PWM is the most often utilised PWM technology. In addition to providing a quick answer, the approach does not need any understanding of system characteristics. The next sections go through the specifics of the hysteresis control approach. Shunt inverter: A voltage-source inverter linked in shunt with the same alternating current line that functions to negate current distortions, compensate reactive current of the load, and increase system power factor. It also regulates the DC-link voltage, resulting in a considerable decrease in DC capacitor rating. The shunt converter's output current is adjusted using a dynamic hysteresis band by regulating the state of the semiconductor switches such that the output current follows the reference signal and stays within a predefined hysteresis band.

DC link capacitor: This capacitor connects the two VSIs that are linked back to back. The voltage across this capacitor provides self-supporting DC voltage for both inverters' optimal functioning.

A low-pass filter is employed to attenuate high-frequency components of voltages at the series converter's output caused by high-frequency switching of VSI.

To absorb waves caused by current switching, a high-pass filter is added at the output of the shunt converter[4].

The required voltage produced by the series inverter to maintain a pure sinusoidal load voltage at the correct value is fed into the line through these series transformers.

4. SYSTEM DESIGN IMPLEMENTATION:

As the demand for power is escalating sharply countries have started exploring alternating sources to match the gap. Besides solar power, wind power is the promising option. Due to the research activities fuel cells have also attracted global attention. Various power quality issues may arise due to integrations of renewables with grid composed of more nonlinear loads. Two renewable energy sources like wind and fuel cells along with a non-linear load were considered to be integrated into an electric grid. This chapter highlights the mitigation of power quality events by incorporating suitable controllers for unified power quality conditioner,

4.1. PROPOSED SYSTEM FOR ANALYSIS:

Unified power quality conditioning is the matter of conditioning the components of the power i.e. Supply voltage and Load current. Figure 1 shows the Simulink model of UPQC. Table I is utilized for modelling of the test system.

The conditions to satisfy conditioning or modelling are as follows:

- If any fluctuation or harmonics occurs in the supply voltage, it should not be affected to the load. So, we need to take care of the voltage to be sinusoidal and controlled at desired value.
- If there is a non-linear load at the load side, then it consumes non-linear current which leads to non-linearity in the grid part and that affects to other loads also. So, we need to take care of the current to be sinusoidal and to make it like there should have minimum amount of THD value.
- Reactive power to be maintained at zero level at Grid point.

5. RESULTS:

5.1. SIMULATION RESULTS AND DISCUSSION

Simulation results are presented below for the system considered for study. The results obtained with and without implementation of UPQC are provided. Simulation has been performed under MATLAB/Simulink environment. The MATLAB/Simulink diagram is shown in Figure 5.1.

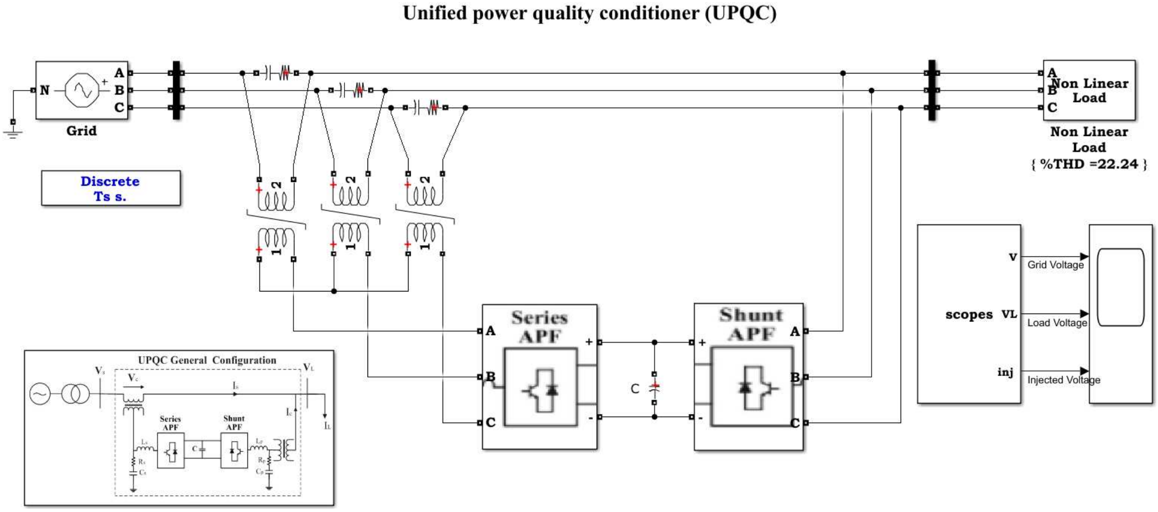

Figure 5.1 MATLAB /Simulink diagram of the proposed system for analysis

The Simulation Parameters for the above MATLAB/Simulink diagram is listed in Table 5.1

Table 5.1 Simulation parameters of the proposed system for analysis

Simulation Parameters	Values
Grid Voltage (Phase to Phase) in RMS	440V
Grid Frequency	50 Hz
Rating of the Coupling Transformer	3.3kVA, 1kV/440V
Non-Linear Load	THD = 22.24 %

➢ Voltage compensation (Series APF)

Series Active power filter (APF) is helpful in compensating the voltage, i.e it will calculate the voltage error that is present in the grid and how much voltage has to induced in the grid to make the voltage sinusoidal with the desired voltage magnitude and frequency.The supply voltage hasto be subtracted by reference voltage (Vabc*), it calculates the error in voltage which is then compared with error voltage produced in the lines and then will proceed to PWM control to produce the pulses to minimize the error produced by the difference in calculated error voltage and produced error voltage.

➢ Current Compensation (Shunt APF)

Current compensation will decide how much current error is present in the grid and how much current has to induced in the grid to make the current sinusoidal with desired current magnitude and frequency.The load current has to be subtracted by reference currents (Iabc*) which will be sinusoidal where Id and Iq currents are purified by collecting load currents, it will calculate the error in current which is then compared with error current produced in 3 lines and then will proceed to PWM control to produce the pulses to minimize that error produced by the difference in calculated error current and produced error current.

➢ DC capacitor voltage controller

The DC capacitor voltage has to be maintained at some desired value. The reference value has to be subtracted by measured DC voltage and the error has to be minimized to zero by a transfer function and the control signal has to be added to Id current.

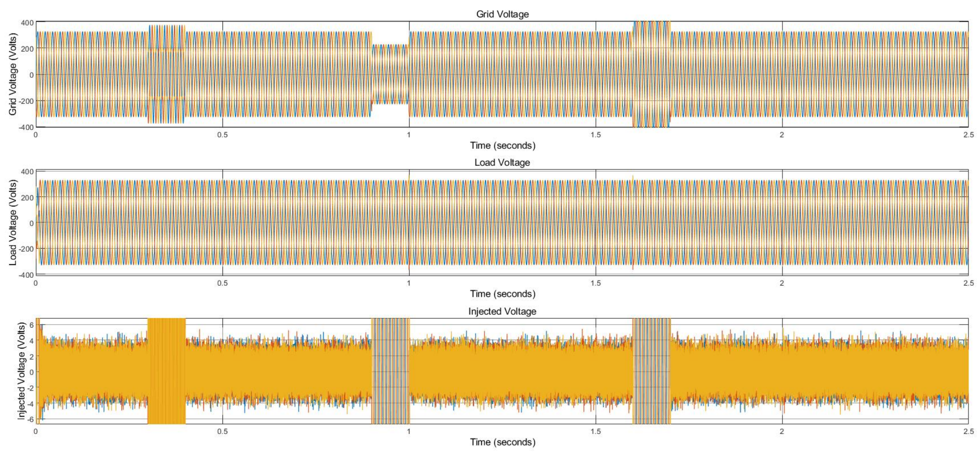

Fig 5.2

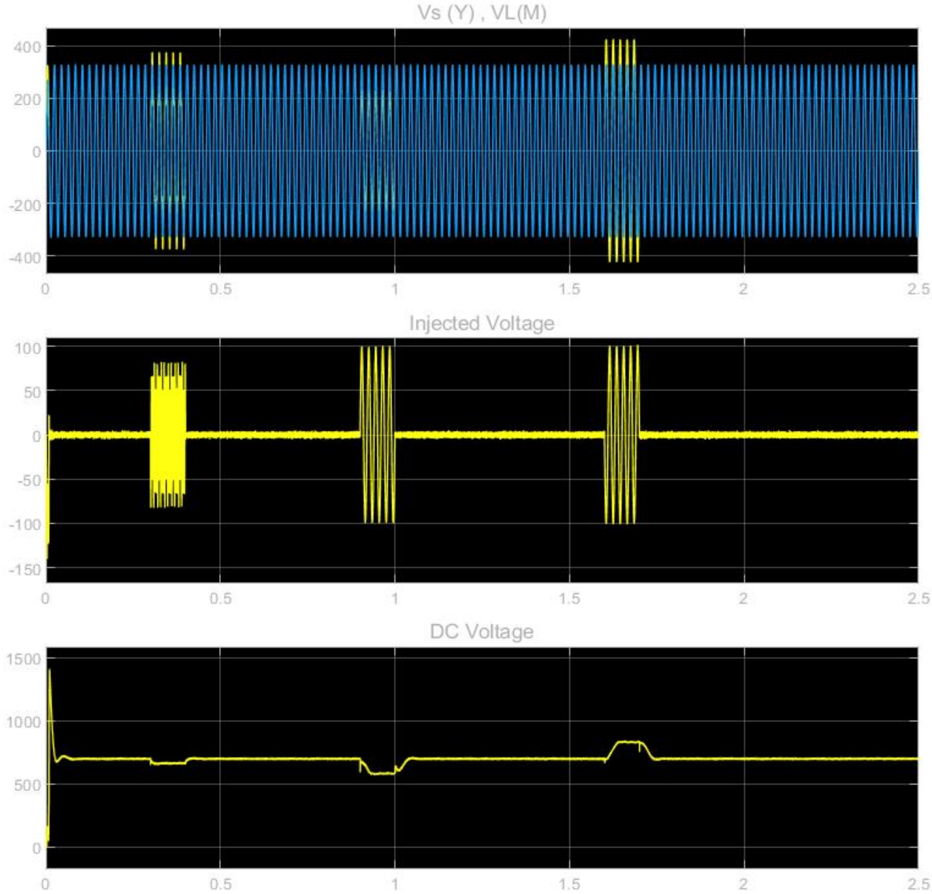

Fig 5.3

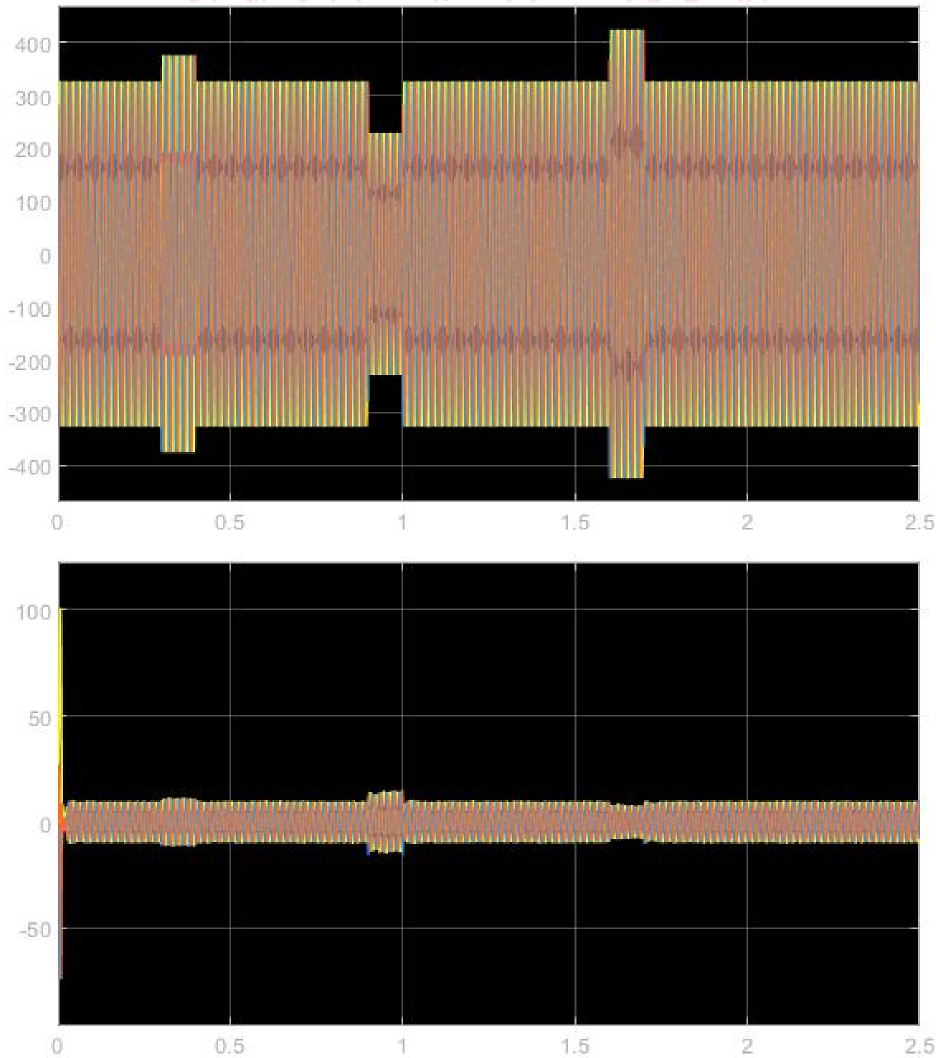

Fig 5.4

5.2. TOTAL HARMONIC DISTORTION

To validate the performance of UPQC, simulations are performed by modeling the test system with MATLAB/Simulink. Total Harmonic Distortion is evaluated to verify the performance of designed control methods. Fig.5.5 shows supply voltage during harmonic conditions after compensation, the series active power filter is responsible in compensating the harmonics. Also shunt active power filter is responsible in alleviating current harmonics, fig 5.5 depicts the harmonic spectrum of current harmonics after compensation, and the percentage THD is below the harmonic limit imposed by IEEE 519-1992.

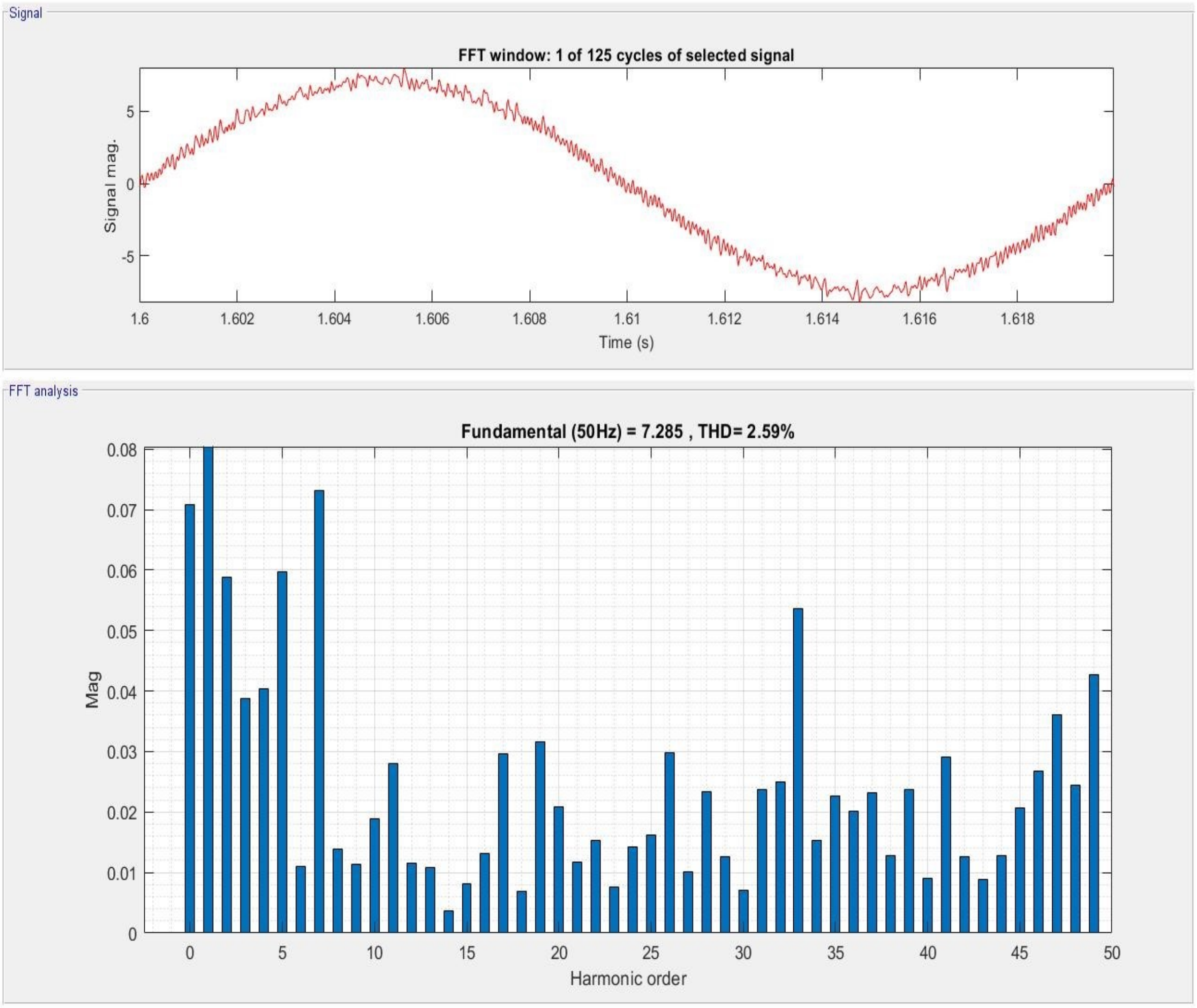

Fig 5.5

6. CONCLUSIONS AND FUTURE WORK

This paper discusses an implementation of series and shunt active power filters as UPQC to compensate for voltage distortions and for alleviating current harmonics. The main focus of this research is to provide a method for detection, classification of power quality events. The source voltage THD after adjustment is well within the IEEE 519 recommended level. The modelling of series APF, shunt APF, and the UPQC has been completed. To simulate the control scheme for series APF, a basic control approach called extraction of unit vector template was utilised. The reference signals for series APF are generated using a phase locked loop (PLL) and a hysteresis band controller in this approach. The instantaneous reactive power theory was utilised to describe the control mechanism for shunt APF. According to the simulation findings, UPQC enhances power quality of power system by correcting harmonic and reactive current of load current, which makes source current sinusoidal, and it also makes load voltage sinusoidal at needed voltage level by compensating with series APF. The THD of the source current and load voltage is less than the harmonics limit established by IEEE standard 519-1992.

The important contributions of this research work are briefed as follows.

- The Proposed expert system offers a better classification in the power quality issues.
- The UPQC offers a solution to power quality problems like voltage imbalances and total harmonic distortion at the point of common coupling. It helps to integrate the renewable energy sources effectively with a minimum power quality impact.

FUTURE SCOPE

Research is a constant process and opens other venue to continue the work. The Further research work may be continued in the following areas.

- The other transformation methods like linear, Walsh and coordinate methods can be implemented for pre-processing stage in expert system. It can be applied for any industries that require power quality monitoring system.
- It can offers a controller that suits to mitigate the power quality events that may rise due to the introduction of the renewable energy source and the nonlinear loads.
- Various evolutionary algorithm can be implemented for the tuning process of the controller implemented in the custom power devices.
- At micro grids, the Power quality issues can be assessed and mitigated using various energy storage systems.
- Energy storage system like super capacitors, fly wheel storage systems can be implemented in custom power devices to have a better performance.

7. REFERENCES

[1] H. Awad, M. H.J Bollen, "Power Electronics for Power Quality Improvements," IEEE Symposium on Industrial Electronics, vol.2, pp.1129- 1136, 2003.

[2] Bhim Singh, Kamal Al-Haddad and Ambrish Chandra, "A Review of Active Filters for Power Quality Improvement" IEEE Trans. on Industrial Electronics, Vol.46, No.5, oct.1999, pp.960-971.

[3] H. Akagi, Y. Kanazawa, A. Nabae, "Generalized Theory of the Instantaneous Reactive Power in Three Phase Circuits", in Proc. IPEC- Tokyo'83 Int. Conf. Power Electronics, Tokyo, pp. 1375-1386.

[4] S. R. Naidu, A. W. Mascarenhas and D. A. Fernandes "A Software Phase-Locked Loop for Unbalanced and Distorted Utility Conditions," IEEE POWERCON Nov.2004, vol. 2, pp. 1055-1060.

[5] Juan W. Dixon, Gustavo Venegas and Luis A. Moran, "A Series Active Power Filter Based on a Sinusoidal Current-Controlled Voltage-Source Inverter" IEEE Transactions on Industrial Electronics, Vol. 44, Issue: 5, Page (s): 612 - 620, Oct. 1997.

[6] ChellaliBenachaiba, BrahimFerdi, "Voltage Quality Improvement Using DVR",Electrical Power Quality and Utilisation, Journal Vol. XIV, No. 1, 2008, pp.30-46.

[7] F. A. Jowder, "Modeling and Simulation of Dynamic Voltage Restorer (DVR) Based on Hysteresis Voltage Control," The 33rd Annual Conference of the IEEE Industrial Electronics Society (IECON) Nov. 2007, pp. 1726-1731.

[8] F.A.L. Jowder, "Design and Analysis of dynamic voltage restorer for deep voltage sag and harmonic compensation", IET Generation, Transmission & Distribution,2009, Vol.3,Iss. 6, pp. 547-560.

[9] Tarek I. El-Shennawy, Abdel-Mon'emMoussa, Mahmoud A. El-Gammal and Amr Y. Abou-Ghazala, "A Dynamic Voltage Restorer for Voltage Sag Mitigation in a Refinery with Induction Motors Loads" American J. of Engineering and Applied Sciences 3 (1) :144-151, 2010

[10] B. Singh, P. Jayaprakash, D. P. Kothari, A. Chandra and Kamal-Al-Haddad, " New Control Algorithm for Capacitor Supported Dynamic Voltage Restorer" Journal of Electromagnetic Analysis and Applications, 2011, 3, 277-286.

[11] M. A. Chaudhari and Chandraprakash, "Three-Phase Series Active Power Filter as Power Quality Conditioner," IEEE International Conference on Power Electronics, Drives and Energy Systems, Dec. 2012, pp. 1-6.

[12] Mehmet Ucar and EnginOzdemir, "Control of a 3-phase 4-leg active power filter under non-ideal mains voltage condition", Electric Power Systems Research 78 (2008) 58–73.

[13] V. Khadkikar, P. Agarwal, A. Chandra, A.O. Bany and T.D.Nguyen, "A Simple New Control Technique For Unified Power Quality Conditioner (UPQC)," IEEE International Conference on Harmonics and Quality of Power, Sept. 2004, pp. 289 – 293.

[14] Yash Pal, A. Swarup, Bhim Singh, "A control strategy based on UTT and of three-phase, fourwire UPQC for power quality improvement" International Journalof Engineering, Science and Technology Vol. 3, No. 1, 2011, pp. 30-40.

[15] Liu Xiaohu; A. Aichhorn,; Liu Liming and Li Hui, "Coordinated Control of Distributed Energy Storage System With Tap Changer Transformers for Voltage Rise Mitigation

Under High Photovoltaic Penetration," IEEE Transactions on Smart Grid, vol.3, no.2, pp.897-906, June 2012.

[16] Yan Ruifeng and T.K.Saha, "Voltage Variation Sensitivity Analysis for Unbalanced Distribution Networks Due to Photovoltaic Power Fluctuations," IEEE Transactions on Power Systems, vol.27, no.2, pp.1078-1089, 2012.

[17] M. J E Alam; K.M Muttaqi and D Sutanto, "A comprehensive assessment tool for solar PV impacts on low voltage three phase distribution networks," 2nd International Conference on the Developments in Renewable Energy Technology (ICDRET), 2012, pp.1-5.

[18] Lin Chia-Hung; Hsieh Wei-Lin; Chen Chao-Shun; Hsu Cheng-Ting; Ku Te-Tien, "Optimization of Photovoltaic Penetration in Distribution Systems Considering Annual Duration Curve of Solar Irradiation," IEEE Transactions on Power Systems, vol.27, no.2, pp.1090-1097, 2012.

[19] S.A Pourmousavi; A. S Cifala and M.H Nehrir, "Impact of high penetration of PV generation on frequency and voltage in a distribution feeder," North American Power Symposium (NAPS), 2012, pp.1-8.

[20] M.H Hairi; Qi Shaofan; Li Haiyu and D.Randles, "Impact of PV generation on low voltage networks," 47th International Universities Power Engineering Conference (UPEC), 2012., pp.1-5.

[21] R Tonkoski; D Turcotte and T. H M EL-Fouly, "Impact of High PV Penetration on Voltage Profiles in Residential Neighborhoods," IEEE Transactions on Sustainable Energy, vol.3, no.3, pp.518-527, July 2012.

[22] R. Tonkoski; L. A C Lopes; T. H M and EL-Fouly,, "Coordinated Active Power Curtailment of Grid Connected PV Inverters for Overvoltage Prevention," IEEE Transactions on Sustainable Energy, vol.2, no.2, pp.139-147, 2011

[23] "IEEE Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks," IEEE Std 1547.6-2011, pp. 1-38, 2011.

[24] E Demirok; P Casado González; K.H.B Frederiksen; D. Sera; P. Rodriguez; R. Teodorescu, "Local Reactive Power Control Methods for Overvoltage Prevention of Distributed Solar Inverters in Low-Voltage Grids," IEEE Journal of Photovoltaics,, vol.1, no.2, pp.174-182, 2011.

[25] M. Tavakoli Bina and A. Kashefi, “Three-phase unbalance of distribution systems: Complementary analysis and experimental case study”, International Journal of Electrical Power & Energy Systems, Volume 33, Issue 4, pp. 817-826, 2011.